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Assessment of disturbance in Mediterranean lagoons: an evaluation of methods

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Abstract A number of methods were applied to assess disturbance in macrozoobenthic communities in three Mediterranean lagoons with different levels of stress. Tsopeli, Ionian Sea, with no obvious source of stress, harbours a fauna typical of brackish-water lagoons. Vivari, Aegean Sea, also without apparent source of disturbance, is characterised by a few typical lagoonal species and some species characteristic of perturbation. Goro lagoon, in the northern Adriatic, is much larger and more open to the sea. At the centre of the lagoon, where anoxia is known to occur in the summer ("Goro polluted"), the fauna is dominated by species typical of disturbance and a few lagoonal species. A dredged area closer to the sea ("Goro dredged") is totally dominated by species characteristic of disturbance. The species diversity in all lagoons ranges from low to very low. According to the distribution of individuals in geometric abundance classes, all the lagoons are characterised as stressed. The distribution of individuals in geometric size classes shows dominance of larger specimens in the least disturbed Tsopeli and exclusively small sizes in the greatly disturbed dredged area of Goro. The abundance/biomass comparison curves characterise Tsopeli as undisturbed, Vivari and Goro polluted stations as moderately disturbed and Goro dredged station as disturbed. The last two methods agree with the characterisation derived by examining the dominant species. It is concluded that methods based on size changes of the fauna are more sensitive than those based on relative abundance in assessing disturbance in coastal brackish-water lagoons.

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Introduction

Mediterranean coastal lagoons are relatively enclosed water bodies. Situated between the land and the sea, they are under the influence of both the marine and the terrestrial environment. Among the main characteristics of coastal lagoons is their shallowness, the shelter from currents and waves, the soft substratum and the well mixed water column due to wind action (Barnes 1980). Lagoons are often nutrient rich (Fiala 1973; Mee 1978) both as a result of input of nutrients by rivers and by recycling between sediment and water mass, facilitated by their shallowness (Murphy and Kremer 1985; Nowicki and Nixon 1985). Thus, coastal lagoons are organically enriched areas where high biomass and productivities are attained (Barnes 1980). As opposed to high abundance, however, diversity is low. This is of particular importance in the oligotrophic eastern Mediterranean which is generally characterised by low abundance and high diversity (Bellan-Santini 1985).

Environmental conditions in coastal lagoons are very changeable due to their confinement from the open sea and to their shallowness. In this sense they could be considered a stressed environment. Furthermore, being close to land, they are vulnerable to human disturbance (Bellan 1972; Stora and Arnoux 1983)

Correlation between organic enrichment and community characteristics over the years has led to a series of empirical models which describe the impact of organic disturbance on benthic communities (Pearson and Rosenberg 1978; Gray 1989). It is generally believed that increased organic enrichment will result in (a) a decrease in the species richness and an increase in the number of individuals, as a result of high densities of few opportunistic species, and (b) a reduction of biomass, except for a small increase at the peak of opportunists. Based on these principles a great number of methods have been proposed in order to describe and quantify the effects of pollution (Warwick 1986;

Warwick and Clarke 1991; Agard et al. 1993; Clarke 1993; Warwick 1993). Simultaneous application of these methods as measures of biological response to perturbation was advocated by Warwick and Clarke (1994).

The aim of the present paper is to investigate the applicability of some of these methods to study disturbance in macrozoobenthic communities of naturally enriched areas such as brackish-water Mediterranean lagoons.

Materials and methods

Sampling sites

Three lagoons were studied with different degrees of communication with the sea and different levels of disturbance (Fig. 1).

Tsopeli lagoon is situated in the Amvrakikos Bay, Ionian Sea, in the vicinity of the Louros River. It covers an area of 1 km^2. Its depth ranges from 0.2 to 1.5 m. Among the lagoons studied, it is the most isolated from the sea. During the period of study it communicated with Amvrakikos through an opening approximately 5 m wide. Due to its confinement and its small depth it showed a wide range of temperatures and salinities. The temperature ranged from 8 °C in January to 29 °C in July and the salinity from 21‰ in December to 35‰ in June. The dissolved oxygen ranged from 3.2 $ml\,l^{-1}$ in June to 9.8 $ml\,l^{-1}$ in January. The sediment was mud covered in most parts with green algae and the eel grass *Zostera nolti*. The lagoon is used for the extensive culture of various species of mullet and eels. Small amounts of gilthead (*Sparus aurata*), bass (*Dicentrarchus labrax*), and sole (*Solea vulgaris*) are also caught. No obvious source of stress was observed in the lagoon.

Vivari lagoon is situated in Argolikos Bay, Aegean Sea. It is approximately half the size of Tsopeli. It is in more direct communication with the fully marine environment, and it receives only a limited amount of fresh water from a runnel of intermittent flow. Here the temperature ranged from 12 °C in January to 34 °C in June. The salinity was higher than in Tsopeli but with a smaller range. It varied from 31.5‰ in November to 40‰ in May. The dissolved oxygen ranged from 4.4 to 8.4 $ml\,l^{-1}$. The sediment was muddy. Vivari is also used, but to a smaller extent, for the extensive culture of grey mullet, gilthead, bass and sole. There was no apparent source of disturbance in this lagoon either. Nevertheless, the disappearance of vegetation, approximately 1 yr prior to sampling was reported.

Goro lagoon is formed at the Po River delta in the northern Adriatic. It is much larger than the other two lagoons with a surface of 25 km^2 and an opening to the sea of 2.5 km. The average depth is 1.5 m. Data from two stations were used here. "Goro polluted" is found in the centre of the lagoon, where circulation is limited and anoxia is known to occur in the summer (data from the Amministrazione Provinciale di Ferrara). In the year of sampling the salinity ranged from 18.4 to 34.7‰. The sediment was muddy and the green alga *Ulva rigida* was often present. "Goro dredged" is situated at the opening to the sea. The water circulation is better here, and anoxic conditions do not occur. The salinity ranged from 19.9 to 35.6‰. The sediment was more sandy. The area is subject to periodic dredging for *Ruditapes philippinarum* which has been acclimatized since 1986 in the littoral lagoons of the northern Adriatic (Reizopoulou 1991).

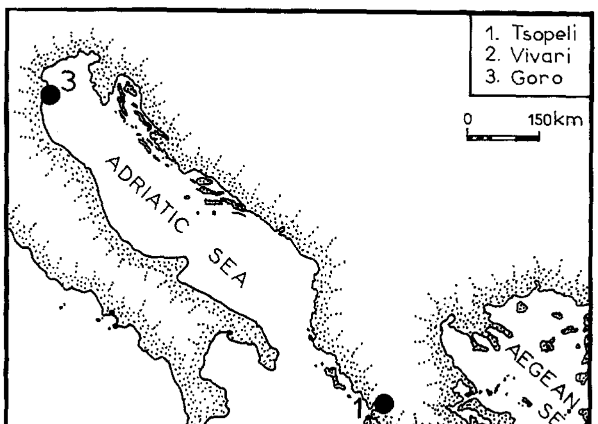

Fig. 1 Areas of sampling

Sampling methods

The lagoons were sampled for macrozoobenthos extensively every month. Seasonal samples taken at one station in each of the Greek lagoons and two in the Sacca di Goro are taken into consideration here.

Samples in Tsopeli and Vivari were collected using a Ponnar grab sampling (0.05 m^2) of the bottom. The total sample size was 0.15 m^2. In Goro a van Arkel 0.02 m^2 sampler was used, and the total sample area was 0.2 m^2. The samples were sieved with a 1 mm mesh sieve and preserved in 4% formalin.

Mathematical methods

The structure of the benthic community in each lagoon was analysed in terms of species composition and abundance, diversity and evenness. The diversity was calculated by the Shannon–Wiener diversity index ($\log_2$ basis) (Shannon and Weaver 1963) and evenness according to Pielou (1969). In order to investigate faunal similarities between lagoons and possible seasonal variability, group average cluster analysis was employed. The Bray–Curtis similarity index was used, and the data were transformed by $Y = \log(x + 1)$.

One of the methods used to assess the degree of disturbance in the lagoons was the abundance/biomass comparison (ABC) as described by Warwick (1986). The k-dominance curves for species abundances and species biomasses were plotted on the same graph, and comparison was made of the forms of the curves. The degree and direction of separation of the ABC-curves was expressed by Clarke's W-statistic (Clarke 1990). This index is scaled so that complete biomass dominance and an even abundance distribution gives a value of $+1$ and the reverse case a value of -1.

Another technique employed was the distribution of species in geometric abundance classes as described by Gray and Mirza (1979) and Pearson et al. (1983). The percentage of species was plotted against the number of individuals per species in geometric abundance classes. To examine the distribution of individuals in geometric size classes, histograms were plotted of the percentage of individuals belonging to each geometric size class. Size was expressed as dry weight (mg). The cluster analysis as well as the descriptive analyses were performed by the software package PRIMER developed in the Plymouth Marine Laboratory. The distribution of individuals in geometric size classes and the correlation between Clarke's W-statistic and size were performed using the software programme STATGRAPHICS.

Results

Animal communities

The most dominant species, forming approximately 90% of the individuals at each lagoon and season, are shown in Table 1 together with their percent abundance. The table also shows the total number of species and individuals at each station and season.

In Tsopeli, the most dominant species at all times was *Abra ovata* followed by chironomid larvae, both characteristic of brackish-water lagoons (Pérès 1967). The abundance of the polychaete *Heteromastus filiformis*, a species tolerant of a wide range of environmental conditions, was also high. Other less abundant species, typical of brackish-water lagoons, were the bivalves *Cerastoderma glaucum* and *Mytilaster minimus*, and the isopod *Sphaeroma ghigii*. Among the rest, the presence of the amphipod *Gammarus insensibilis* and the isopod *Idotea baltica* which are generally found in brackish-water environments and among vegetation (Ruffo 1982; Salemaa 1987) is noted.

Vivari was totally dominated by *Abra ovata* and *Heteromastus filiformis*, except in autumn when *A. ovata* decreased in dominance and *Nereis diversicolor* became important.

An almost completely different set of species dominated the fauna of the northern Adriatic lagoon with the exception of the chironomids in the polluted station. In this organically enriched station of Goro the most numerically important species were the polychaetes *Capitella capitata*, *Polydora ciliata* and *Ficopomatus enigmaticus*, all characteristic of disturbance (Pearson and Rosenberg 1978). Other seasonally important species were the amphipods *Microdeutopus gryllotalpa*, *Gammarus insensibilis*, *Gammarus aequicauda* and the gastropod *Hydrobia* sp.

Finally, the dredged station in Goro was also dominated by the polychaetes *Capitella capitata*, *Polydora ciliata* and *Streblospio shrubsoli*. The polychaete *Spio decoratus* was important in spring and summer while in autumn the amphipod *Corophium insidiosum* was the most dominant.

Diversity was low in all the lagoons (Fig. 2a) with small seasonal fluctuations. Lowest diversity values were always observed in Vivari, where the fauna was dominated by very few species, as seen in Table 1, resulting in very low evenness values (Fig. 2b). The

Table 1 Most abundant species (percent abundance) accounting for at least 90% of the individuals in each station in the three lagoons

Species	Tsopeli				Vivari				Goro polluted				Goro dredged			
	Spr	Sum	Aut	Win	Spr	Sum	Aut	Win	Spr	Sum	Aut	Win	Spr	Sum	Aut	Win
Abra ovata	39.6	47.2	43.3	31.0	78.2	77.8	6.3	42.2								
Cerastoderma glaucum	2.1	7.1		4.4												
Hydrobia sp.									2.5	18.4	50.0	6.6				2.5
Mytilaster minimus			4.2							3.1						
Ruditapes philippinarum																14.8
Capitella capitata	6.1		5.6	4.4					35.9	3.1	15.9	11.3	13.4	8.1	7.2	9.1
Chaetozone setosa				4.4	2.6											
Exogone verrugera							3.4	2.3								
Ficopomatus enigmaticus										5.9	4.4	38.3				
Heteromastus filiformis	14.5	12.8	11.6	7.6	8.8	14.3	65.7	39.9						2.2		
Microspio mecznicowianus	1.3	2.8														
Nereis diversicolor	1.4					3.2	21.1	7.3								
Nereis succinea										3.1					1.6	6.0
Polydora ciliata									44.4			2.1	33.2	14.7	27.4	29.5
Spio decoratus													9.6	12.8		
Streblospio shrubsoli													30.5	48.3	7.7	22.4
Corophium insidiosum															48.6	
Gammarus aequicauda										13.3						
Gammarus insensibilis	2.1			4.4								15.2				
Idotea baltica	2.1			3.2												
Microdeutopus gryllotalpa					5.2					3.1		10.3				
Paramysis helleri		2.5														
Sphaeroma ghigii			3.3	6.3												
Chironomus sp.	17.8	18.4	21.4	29.1				2.7	11.0	39.6	26.1	11.9				
Nemertea	3.7		2.8													
Oligochaeta	2.4												5.6	7.0	2.6	4.5
No. of species	26	10	12	12	16	15	8	17	19	20	10	18	31	23	33	32
No. of individuals m^{-2}	3129	1469	1428	1048	7474	4133	1163	4007	6054	1344	2657	5679	13341	8152	57101	14502

dominance of different species in each lagoon is registered in the multivariate community analyses. In the dendrogram of Fig. 3, the seasonal samples in each lagoon cluster separately from those of the other lagoons. In addition, the two Greek lagoons, Tsopeli and Vivari, are more similar to each other (similarity $\sim 40\%$) than with the northern Adriatic lagoon (similarity $\sim 25\%$).

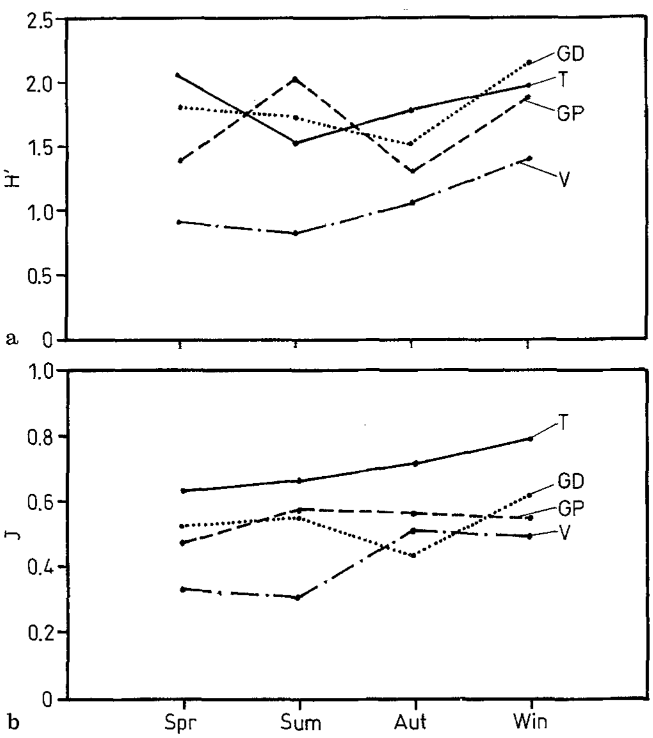

Fig. 2 a Fauna diversity (H') and **b** evenness (J) in all lagoons (*T* Tsopeli; *V* Vivari; *GP* Goro polluted; *GD* Goro dredged) and seasons

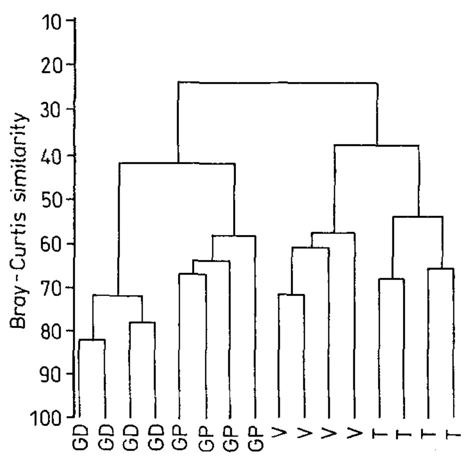

Fig. 3 Clustering of seasonal samples in each lagoon (*T* Tsopeli; *V* Vivari; *GP* Goro polluted; *GD* Goro dredged)

Abundance/biomass comparison

To assess the community disturbance in the lagoons the ABC-method was applied to the data for each station and each season. The resulting curves are shown in Fig. 4. According to these curves, Tsopeli is clearly undisturbed as the biomass curves overlie the abundance curves for their whole length. In Vivari, the two curves tend to be superimposed, suggesting moderate disturbance. The same applies to the polluted station in the northern Adriatic lagoon Goro. The most disturbed locality is the dredged station in Goro where the abundance curves overlie those of the biomass except in the winter when the biomass and abundance curves are superimposed.

The degree and direction of separation of the ABC-curves are expressed by Clarke's *W*-statistic. The changes of *W* with time are given for each lagoon in Fig. 5. Positive values, between 0.1 and 0.3, were always found in Tsopeli, indicating unperturbed conditions. The dredged station in Goro always had negative values of *W*, while in Vivari and the polluted station of Goro the values fluctuated around zero.

Mean size of individuals

Size of individuals is generally smaller in organically polluted areas (Pearson and Rosenberg 1978). The distribution of individuals in geometric size classes is shown in Fig. 6. In Tsopeli a large number of classes are almost equally represented. The dominance of small individuals is most pronounced in the dredged station of Goro. In Vivari and the polluted station of Goro an intermediate situation exists with more size classes present in the latter.

In an attempt to relate the average individual size with the disturbance expressed by the ABC-curves, the mean individual dry weight (as an expression of size) was correlated with the *W*-statistic. The two variables showed significant positive correlation ($r = 0.79$) on log scales. As shown in Fig. 7, data from the undisturbed Tsopeli lagoon appear in the upper portion of the plot, with considerable variance in mean individual size.

Distribution of abundance classes

With respect to the distribution of species in geometric abundance classes (Fig. 8), the difference between lagoons is not as clear as with the previous methods. There is only a tendency towards higher abundance classes in the dredged station in Goro, in contrast to the undisturbed Tsopeli lagoon.

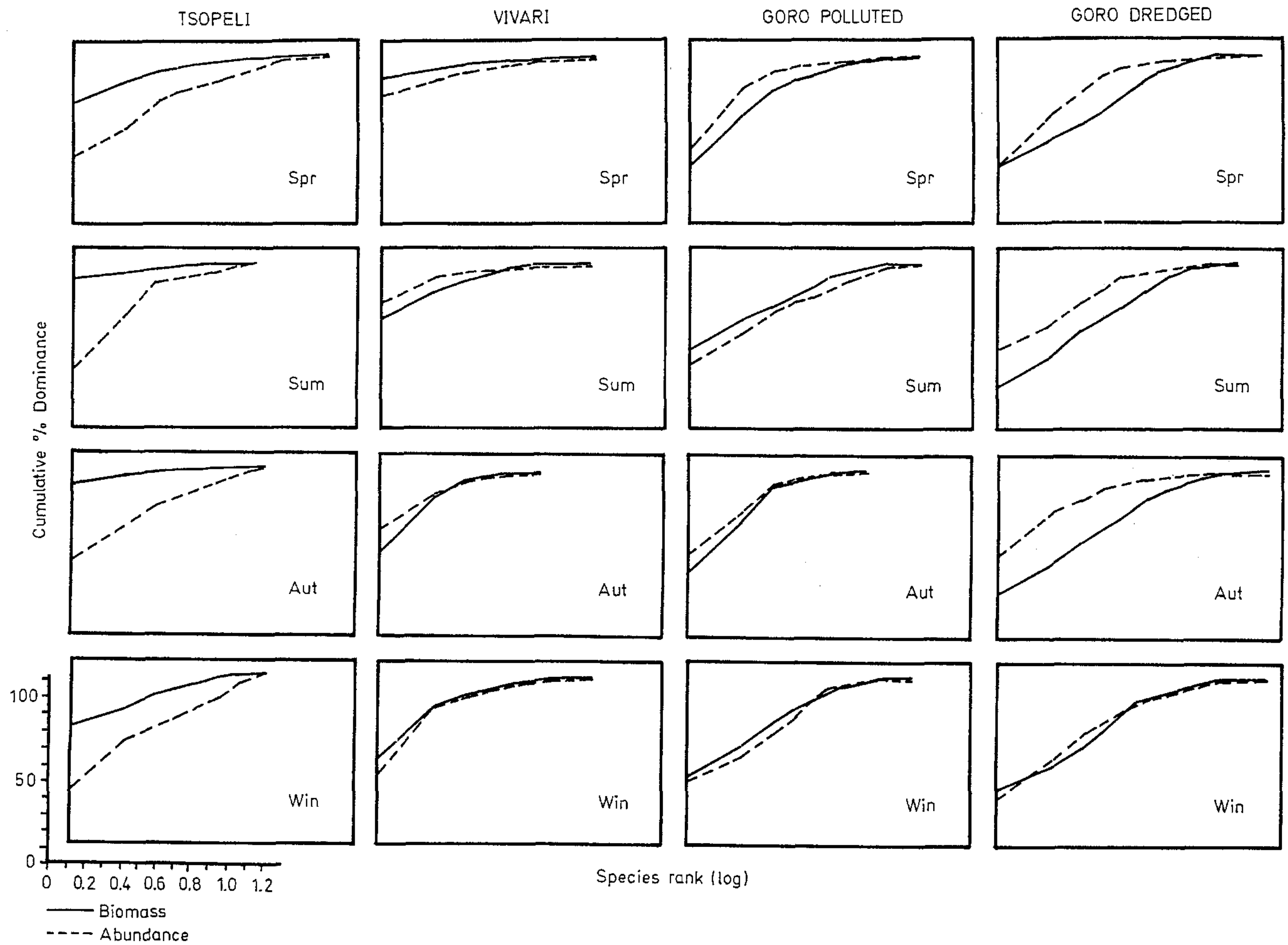

Fig. 4 ABC curves for all lagoons and seasons

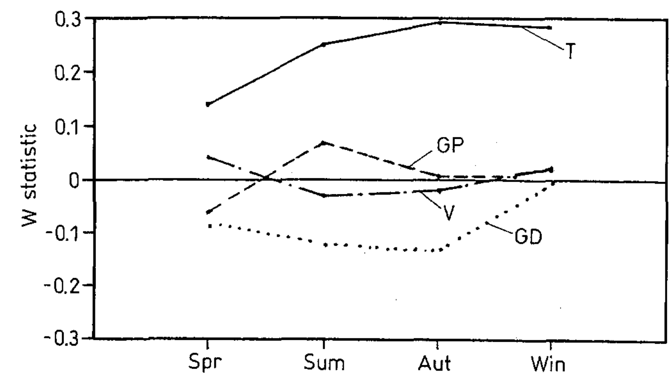

Fig. 5 Clarke's *W*-statistic for all lagoons (*T* Tsopeli; *V* Vivari; *GP* Goro polluted; *GD* Goro dredged) and seasons

Discussion

The three lagoons supported different fauna. The community in Tsopeli was much more typical of brackish-water lagoons with characteristic species (Pérès, 1967), *Abra ovata*, chironomidae larvae, *Cerastoderma glaucum*, and *Mytilaster minimus*, representing together 60 to 70% of the individuals. The presence of *Heteromastus filiformis*, a species with a wide ecological tolerance range commonly found in organically enriched areas, was noticeable.

Vivari had two species typical of euryhaline and eurythermal lagoons, *Abra ovata* and *Neanthes diversicolor*. The above species together with *Heteromastus filiformis* totally dominated the fauna. On very few occasions other lagoonal species were found. Thus, the fauna could not be considered as typical of lagoons. In the northern Adriatic lagoon many of the dominant species such as *Capitella capitata*, *Polydora ciliata* and *Ficopomatus enigmaticus* have been characterised as indicators of disturbance (Pearson and Rosenberg 1978). In the Goro polluted station the above species were accompanied by a few species characteristic of lagoons, namely *Mytilaster minimus* and the chironomid larvae. Those were practically missing from the dredged station.

The diversity of the fauna, which ranged from 0.83 to 2.14, was very low compared to other shallow, non-lagoonar Mediterranean areas. Diversity in the Amvrakikos Bay, for example, at depths between 2 and 9 m

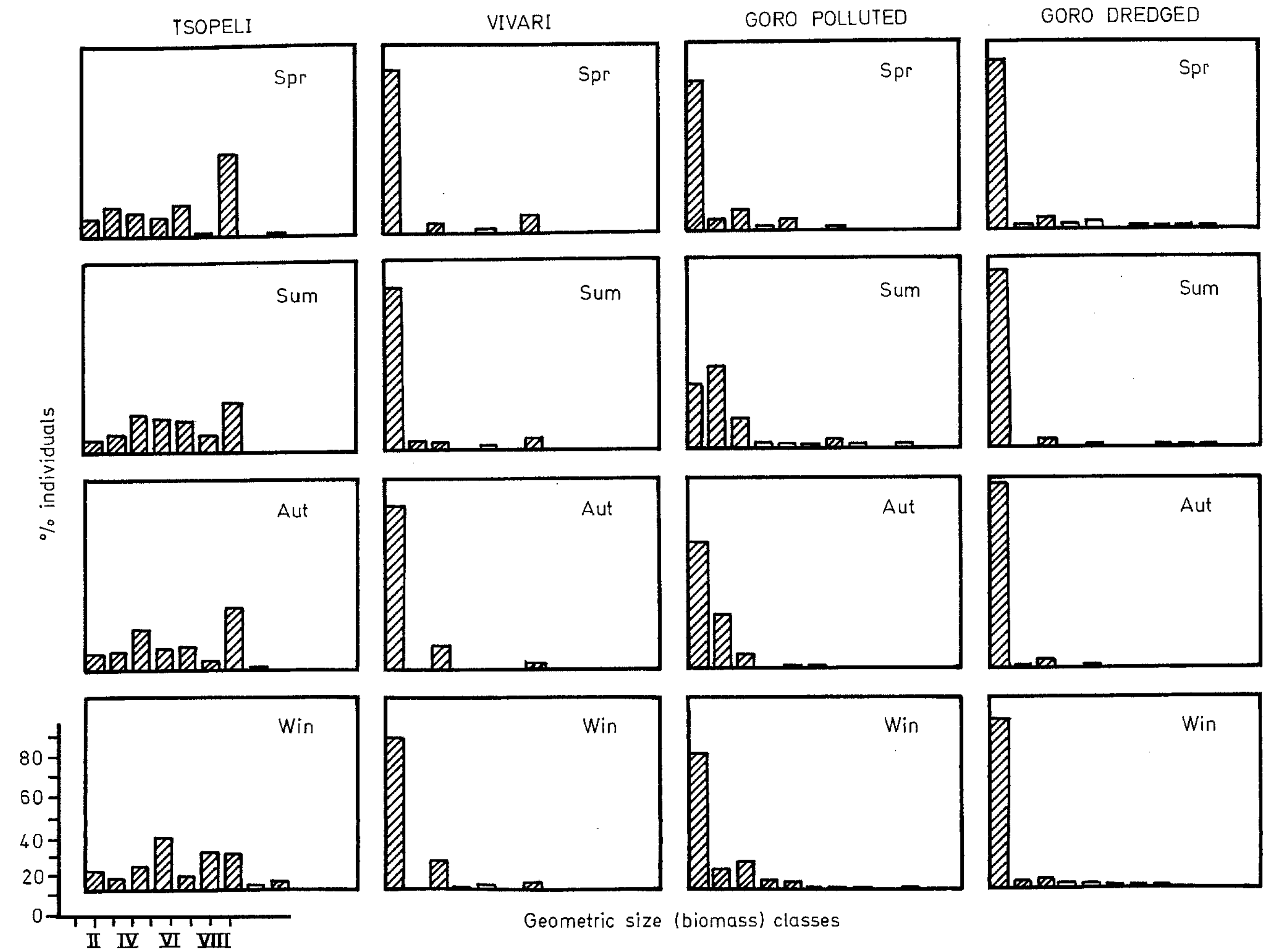

Fig. 6 Distribution of geometric size classes for all lagoons and seasons

ranged from 3 to 5 (Nicolaidou et al. 1983) and in the Bay of Geras (Papathanassiou and Zenetos 1993) at depths from 6 to 11 m it was 5 to 6. However, diversity was comparable to that of other Mediterranean lagoons. In the Mazoma Lagoon of the Amvrakikos Bay it ranged from 2.18 to 2.93 (Nicolaidou and Karlou 1983).

There is some controversy on whether the ABC-method has a universal application in identifying community disturbance. Since its introduction (Warwick 1986) it has been successfully applied on many occasions in temperate and tropical soft bottom communities (Warwick and Ruswahyuni 1987; Anderlini and Wear 1992), in mesocosm experiments (Gray et al. 1988) and at fish culture sites (Ritz et al. 1989). On other occasions, however, (Beukema 1988; Ibanez and Dauvin 1988; Weston 1990; Craeymeersch 1991) it did not correctly characterise the disturbance status of some sites. In the present study, the condition of disturbance in the three lagoons as characterised by the ABC-method was in agreement at least with the

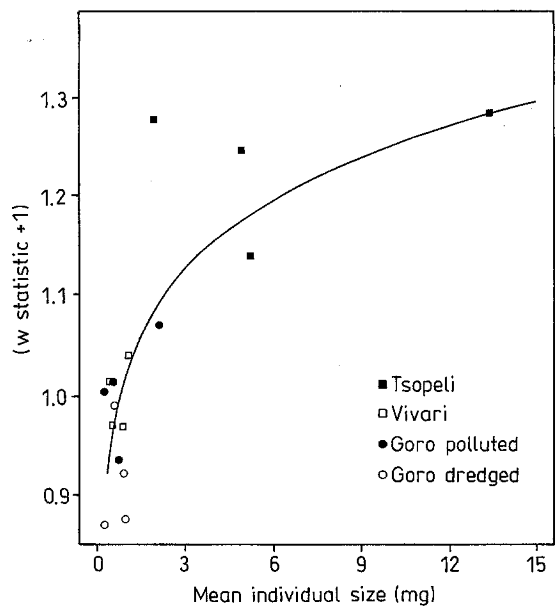

Fig. 7 Regression of Clarke's W-statistic on mean individual size. W-statistic + 1 used as dependent variable to make ln transformation possible

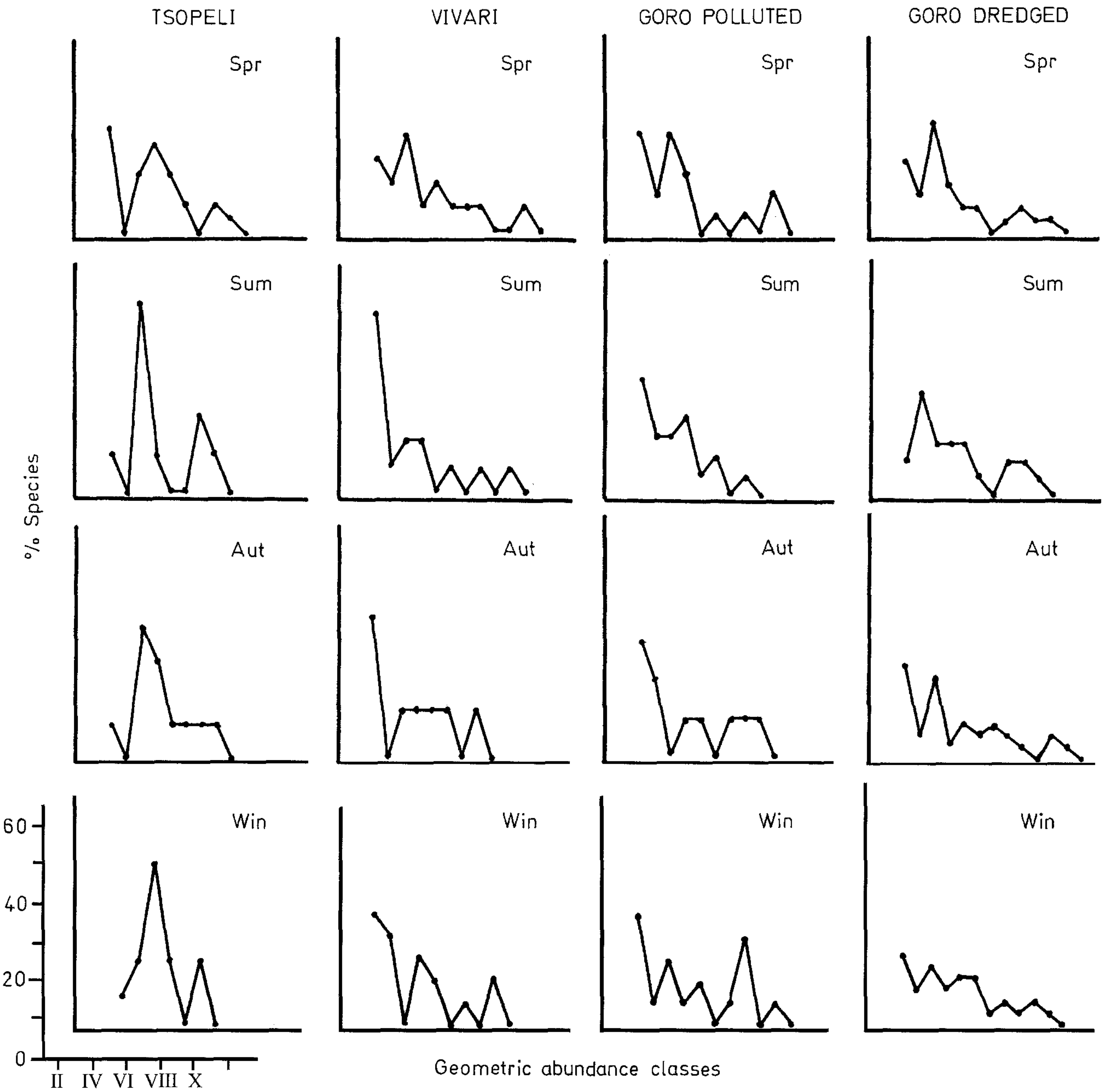

Fig. 8 Distribution of abundance classes for all lagoons and seasons

descriptive evaluation based on species composition. Tsopeli, with typical lagoonal fauna, was characterised as undisturbed by the ABC-method. At the other extreme, the Goro dredged station, where species characteristic of disturbance dominated, was characterised as perturbed. The other two sites showed intermediate characteristics both in their fauna composition and in the position of ABC-curves. This classification of the lagoons remained practically unchanged during the four seasons of the investigation.

Pearson and Rosenberg (1978) suggested that the average individual size decreases in polluted areas. Warwick et al. (1986) assumed that this applies to mean species size and that with increasing organic enrichment large species are lost and are replaced by smaller opportunistic species. The distribution of individuals in geometric size classes in the lagoons studied showed that greater number of larger specimens was found in what was considered the least disturbed area, Tsopeli, while these classes were drastically reduced in the moderately disturbed sites. Small sizes completely dominated the distributions in the greatly disturbed dredged area. In the last case, however, the very small size may also be attributed to the continuous dredging which may not give individuals enough time to grow.

Positive correlation between the mean individual size and Clarke's index showed indeed that smaller

Table 2 Main attributes of each lagoon and its characterisation

Attribute	Tsopeli	Vivari	Goro polluted	Goro dredged
Salinity (‰)	21.0–35.0	31.5–40.0	18.4–34.7	19.9–35.6
% sediment organic matter	6.06	8.21	14.10	9.50
Species diversity	low	very low	low	low
Dominant species	typical of lagoons	typical of lagoons and disturbance	typical of disturbance and lagoons	typical of disturbance
ABC and W-statistic	undisturbed	moderately disturbed	moderately disturbed	disturbed
Mean individual size	many size classes, equally represented	dominance of small size classes	dominance of small size classes	very few, small size classes
Distribution of abundance classes	stressed	stressed	stressed	stressed

disturbance, indicated by higher values of the W-index, corresponded to larger mean individual size.

The graphical method of plotting the number of species against the number of individuals per species in geometric abundance classes, proposed by Gray and Pearson (1982) to detect stress impact on benthic assemblages, was not very successful in distinguishing differences between lagoons. The method relies on the fact that unstressed communities have many rare species and few common ones, while in stressed environments the rare species are eliminated and many – opportunistic species – become extremely common. In the present case the difference between the curves was registered above all at the high abundance classes, the disturbed sites having a greater number of high abundance classes. The opposite was observed by Nicolaidou et al. (1993) in an oligotrophic area subject to pollution by solid wastes. There, the basic difference in the curves of the polluted sites involved only a drop in numbers of rare species and not an increase of high abundance classes. The authors attributed this fact to the lack of organic matter which would promote settlement and growth of opportunists. In the present case, there is enough "food" for the individuals but the lagoonar environment already imposes some stress to the organisms which causes the rarer species to disappear.

A summary of the main attributes of each lagoon, together with a characterisation of the degree of disturbance according to the various methods used, is shown in Table 2. Concerning environmental conditions, the salinity range was similar in all the areas except for Vivari which had higher salinity with a smaller range. Percentage of organic matter in the sediment was lower in Tsopeli and higher in the organically enriched Goro polluted station, with Vivari and Goro dredged having intermediate values. The stress exerted by these factors is not in direct correspondence with the results of the present analyses, i.e. highest organic matter does not correspond to the most disturbed lagoon, and smaller salinity range does not coincide with the least stressed community. On the other hand, there is a convergence of some of the statistical methods. The ABC-curves, the W-statistic based on them, and the distribution of individuals in size classes concurred in their characterisation of the lagoons and proved sensitive enough to discriminate between different levels of disturbance, although, as indicated by the classification analysis, different communities were involved. Furthermore, they were in agreement with the description provided by the dominant species. The species diversity and the distribution of individuals in abundance classes, on the other hand, did not lead to a clear distinction between the lagoons. Thus, methods based on size changes were more sensitive than those based on changes in relative abundance. It may be interesting, therefore, to investigate the size diversity, as opposed to species diversity, in expressing environmental stress. This, being less time consuming and requiring less expertise than other methods, could be applied to provide a quick, even if preliminary, assessment of disturbance.

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